PROGRESS OF THE S-BAND RF SYSTEMS FOR THE FERMI@ELETTRA LINAC*

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Abstract

FERMI@Elettra is a seeded FEL user facility under construction at Sincrotrone Trieste, Italy. The linac is based on S-band normal conducting technology. It will use the accelerating sections of the original Elettra linac injector, seven sections received from CERN after LIL decommissioning and two additional sections to be constructed for a total number of 18 S-band accelerating sections. Installation of the machine is presently being carried on. This paper will provide a summary of the requirements of the different parts of the S-band RF system and of the options for a possible upgrade path both in energy and reliability. The ongoing activities on the main subassemblies, in particular regarding the tests and the installation work, will also be presented..

OVERVIEW

FERMI@Elettra will be a single pass FEL users facility providing high quality photons in the UV to soft X-ray range [1]. The accelerator consists of one RF gun, 5 S-band linacs, one X-band system, a laser heater, two bunch compressors and the beam transport system to the undulators. The S-band linacs [2] are being constructed upgrading the original Elettra linac injector with additional nine sections, seven of which were provided by CERN and two will be acquired. The repetition frequency will be upgraded to 50 Hz (from the original 10 Hz), therefore also the RF power plants have to be upgraded. In addition the requirements on amplitude and phase stability require new developments on the low level RF system.

S BAND RF SYSTEM

The S-band RF system is composed of 18 accelerating sections and 15 power plants (Figure 1). The seven sections equipped with SLED cavities are powered by a single klystron. The remaining sections are powered in pairs by a common klystron, with the exception of the last section that uses the same klystron with the high energy deflecting cavities. One klystron powers the gun and the low energy deflecting cavities. An additional klystron is used as a spare system to replace the first two klystrons.

Accelerating Sections

The linac is divided in five parts. Linac 0 comprises the first two accelerating sections (S0A and S0B) after the gun and up to the laser heater. These sections are the first two sections of the original Elettra linac. They are travelling wave sections operating in the 2/3π mode and coupled on axis [3].

Linac 1 is formed by the next four accelerating sections up to the bunch compressor and linac 2 by the following four accelerating sections. Seven of these sections (C1 to C7) are CERN sections, while the last one (C8) has to be acquired. Also the CERN sections are travelling wave sections operating in the 2/3π mode and coupled on axis.

Linac 3 comprises the two sections up to the second bunch compressor and linac 4 the remaining six sections. Seven of these sections (S1 to S7) are from the original Elettra linac and are equipped with a SLED type RF pulse compression system. These sections are backward travelling wave sections operating in the 3/4π mode and they are magnetically coupled. This operating mode was chosen by the manufacturer to optimise the section efficiency and to achieve a simple RF tuning setup. The last accelerating section (C9) has to be acquired.

The sections, in particular the BTW ones have been investigated to understand the limits in their operation in the past [4]. The high energy stability required (better than 10^{-3}) implies tight tolerances on temperature stability. RF heating will imply thermal deformation of the sections, both in the transversal and longitudinal directions. For this reason the temperature must be in range of ±0.05 °. To fully characterize the thermal performances, an extensive study of the thermo-mechanic behaviour of the accelerating sections has been carried on [5]. This has also lead to develop an algorithm to control the longitudinal deformation of the sections.

The main parameters of the sections are summarised in table 1. The linacs are installed in the accelerator tunnel, 5 m below the ground level.

Table 1: Existing Sections' Parameters

Parameter	S0A-S0B	C1-C7	S1-S7
Mode	TW 2/3π	TW 2/3π	BTW 3/4π
Frequency	2998 MHz	2998 MHz	2998 MHz
Cell length	33.33 mm	33.33 mm	37.5 mm
N. of cells	93(94)	135	164
Total length	3.2 m	4.5 m	6.15 m
Acc. gradient	15 MV/m	12 MV/m	24 MV/m
Energy gain	45 MeV	55 MeV	140 MeV

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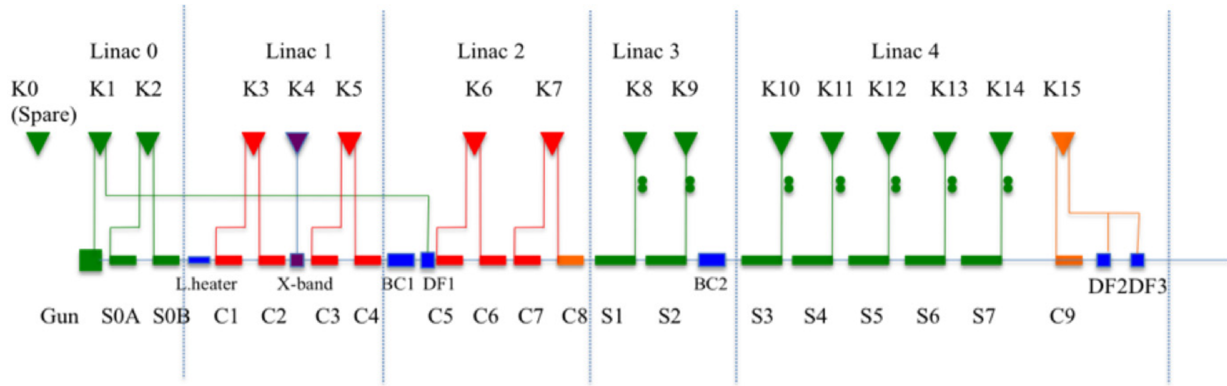

Figure 1: Linac layout.

Power Plants

The needed RF power is provided by 14 Thales TH2132A klystrons (3 GHz, 45 MW peak power in a 4.5 µsec pulse width) plus a spare klystron that is meant to replace the first two tubes in case of failure. The main parameters of the klystrons are reported in table 2.

Table 2: Typical TH2132A Klystron Parameters

Parameter	
Frequency	2998 MHz
Peak RF power	45 MW
Mean RF power	10 kW
RF pulse width	4.5 µsec
Pulse repetition frequency	50 Hz
Gain at full output power	≥ 53 dB
Efficiency in saturation condition	≥ 43 %
Beam voltage (typical)	310 kV
Peak cathode current	350 A
Perveance	2µPerv
Maximum admissible VSWR	1.5:1

For the first commissioning periods, the repetition rate of the linac will be 10 Hz. For this reason six 10 Hz PFN (pulse forming network) modulators are being assembled re-using most of the components of the old linac modulators. They will be eventually upgraded to 50 Hz. In parallel the components for seven 50 Hz PFN modulators are being acquired. These modulators will be assembled starting from the second half of this year.

The two 50 Hz modulator prototypes, a PFN one, now used for klystron testing, and a solid state one, now under development, will be used for the spare klystron and for the last plant.

The PFN modulators are based on conventional technology using a thyratron as switching element, a low ripple pulse forming network and a high voltage transformer.

The solid-state modulator [6] is being developed in the frame of an R&D program. It is an Insulated Gate Bipolar Transistor (IGBT) based inductive adder design with a conventional pulse transformer between the adder and the klystron cathode. There are eight induction cells each one driven by two parallel IGBTs. The design is advancing and in the next months it should be possible to have the modulator running with all cells driven by two IGBTs each at full power into a resistive load.

Table 3: Typical PFN Modulator Parameters

Parameter	
Maximum output voltage	320 kV
Maximum delivered current	350 A
Repetition frequency	50 Hz
RF pulse width	4.5 µsec
Risetime / falltime	< 2 µsec
Pulse flatness	< ± 0. 1 %

RF Power Distribution

The design of the waveguide run has been completed. To maintain phase stability, all the components will be water-cooled and a temperature stabilization loop will be implemented.

Low Level RF

The requirements on pulse-to-pulse stability of the cavity RF fields are very stringent. The entire phase and amplitude budgets are 0.1° and 0.1% respectively. Therefore the Fermi Low Level RF system (FLLRF) is a crucial part of the machine. In order to meet the specification state of the art digital technologies are adopted [7], [8]. The system is developed in the frame of a scientific agreement between Sincrotrone Trieste and Lawrence Berkeley National Lab.

The FLLRF will be an all-digital system composed mainly of two PC boards: a RF front-end board and a digital processing board. The RF board has five RF input channels and two RF output channels. In addition there are various triggers, diagnostic and base-band I/0. The board performs frequency conversion between RF and IF signals and it hosts all the frequency dependent components, such as filters, mixers and amplifiers.

The digital processing board implements a high speed FPGA, which performs all control, diagnostic and external communication. The control systems along the linac are connected through high speed serial links to a central controller being developed at CERN/LANL called "The Matrix".

STATUS OF THE ACTIVITIES

The progress of the activities is dictated by the commissioning plan and by the advancing of buildings' construction. In summer 2009 the first commissioning period will start during which basically all the components up to the laser heater, i.e. linac 0, will be set into operation. The commissioning of the linac will then proceed in different phases with the target of being completed at the end of 2010.

The accelerating sections are being positioned at beginning of May. The first two 10 Hz modulator will be assembled at beginning of June. In parallel the acquisition of the components and the assembly of the other modulators is advancing. The klystrons already available have been measured and characterized. All waveguide components needed for the first phase have been ordered and should be available by the end of June.

Although there is no need of the high stability LLRF system during the first commissioning period, a prototype should be available by the end of summer to allow preliminary test of the design.

UPGRADE PATH

Different possibilities of upgrade have been examined to increase the safety margins and for the future developments, especially related to the requirements of FEL 2. These were also examined with the help of a committee of experts from other facilities (CERN, ANL, SLAC).

The original BTW sections in the past had difficulties to reach the design gradient. To lower peak field and make the compressed pulse flatter, phase modulation of the SLED drive has been investigated [9]. This technique will allow to maximise energy gain keeping the peak fields lower than the breakdown gradient. The calculations performed show that, arranging the phase modulation parameters, one could increase the energy gain of the section by 10 %, with the peak field 12 % lower. This means that an energy gain in excess of 160 MeV per section could be reached still with no breakdown problems.

To increase the energy margin, the possibility of increasing the power gain through the C type sections, either by adding a SLED system or powering each one with one klystron, will be investigated. However this has to be seen in conjunction with the space limitations of the klystron gallery.

Other possibilities to increase the reliability of the systems will be examined in the near future, such as the possibilities of a "hot spare" klystron with a waveguide switching system or a "ready to use klystron" for fast replacement in case of failures.

CONCLUSIONS

FERMI@Elettra is now in the construction phase. The first commissioning period will start next July.

The construction of the S band RF systems is progressing in parallel with the continuing studies on reliability aspects, which will be particularly important for a users' facility as FERMI@Elettra will be.

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